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ABSTRACT

FLUIDMOD is an interactive program for student practice and instruction in the medical treatment of fluid and electrolyte problems in human patients. Previous instructional programs in this field have been based on teaching numerous rules applicable to particular problems, which must then be applied by the student to actual patients who supply feedback responses to the therapy. The FLUIDMOD program uses a mathematical model of the patient so that a student at a graphics console may work completely through the sequence of steps of a given therapeutic problem. Thus, he is actively involved in simulated patient management. FLUIDMOD also contains interactive programs to simulate the clinical patient-management environment: doctor's orders, nursing notes, the patient chart and record, etc., are provided. Eventually, FLUIDMOD will contain instructional programs to which the student may branch as required. The utility of using such a system in teaching hospital environments is now being evaluated. (Author)

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FLUIDMOD: A VERSATILE CAI SYSTEM FOR MEDICAL STUDENTS

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Abstract

FLUIDMOD is an interactive program for student practice and instruction in the medical treatment of fluid and electrolyte problems in human patients. Previous instructional programs in this field have been based upon teaching numerous rules applicable to particular problems; these rules must then be applied by the student physician to actual patients, who supply the feedback response to a given therapy. The FLUIDMOD program, however, uses a mathematical model of the patient so that a student, sitting at a graphics console, may work his way completely through the sequence of steps of a given therapeutic problem. In this manner, he is actively involved in simulated patient management. In addition, FLUIDMOD contains interactive programs to simulate the clinical patient-management environment: doctor's orders, nursing notes, the patient chart and record, etc., are provided. Finally, FLUIDMOD will eventually contain instructional programs to which the student may branch as required.

We are now instituting evaluation procedures to determine the utility of such a system in a teaching-hospital environment. The program occupies less than 200K bytes with overlay, and we expect the student cost per time-shared console to be about one dollar per hour.

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I. INTRODUCTION

FLUIDMOD is a computer-based interactive program for the display and simulated treatment of medical problems in fluid and electrolyte management. For the nonmedical audience, fluid and electrolyte problems arise in the human body when either the water or electrolyte contents of various subcompartments of the body are "out of balance" and the intrinsic control systems of the body cannot or will not return the "balance" to normal. By balance may be meant either the normal total amount, distribution among the subcompartments, or the concentrations of electrolytes (principally sodium, potassium, chloride, bicarbonate, and hydrogen) and water. Normally the amounts, distributions, and concentrations of water and electrolytes are closely controlled by various internal mechanisms, but critical disparities very frequently occur in acutely ill people and must be attended promptly.

Because of the potentially serious consequences of water and electrolyte imbalance, the attending physician must be able to form an hypothesis as to the nature of the particular imbalance quickly and, particularly in the very young patient, begin therapy immediately. On the other hand, the problem can be quite complex, and the information available to the physician is scanty at best. There are many cross-coupled control systems involved, and actually many electrolytes, proteins, colloids, and molecules as well as diverse other functions of the body must be considered simultaneously. Treatment consists primarily of withholding or giving various combinations of therapeutic fluids, each of which is water containing dissolved electrolytes or molecules.

Treatment normally follows a set of time-tested rules plus whatever rational deductions may be drawn from laboratory and other information regarding each particular patient. But because of the complexity and frequently the urgency of the situation, the chosen therapy may not be optimum. It would be well, consequently, to arrange realistic simulations of this entirely typical situation so that students and others may practice and, if the simulation is sufficiently realistic, learn more about the details of the decision process required of them in similar cases.

FLUIDMOD is a program directed to these goals, practice with complicated, realistic problems, and in-depth instruction at the points of indecision or error in judgment. These two modes, practice and instruction, are distinct but necessarily interdependent, and each presents about the same difficulty in software preparation. The primary difficulty is to create sufficiently profound and interesting "cases" and instructional programs so that the student will become involved at a learning rather than superficial level.

II. BACKGROUND

Several specialized programs have been written for student practice on the fluid and electrolyte problem. Generally, these programs emulate the current clinical practice of physicians in that they have incorporated the several general rules and bases for decision which have been accumulated over the years. Given certain patient data, the program will make a determination as to the amount and kind of fluid to be administered according to current practice.

The best of these programs, e.g., Refs. 1 and 2, are quite sophisticated in that a student at an interactive typewriter terminal is led through a fairly complicated maze of questions and answers to formulate his own therapeutic regime. These programs are quite dependable, and the user may then treat the patient, returning at a later time with updated patient information to again determine the best next move.

In considering this situation, it is clear that an improvement would be achieved if the interactive program incorporated a sufficiently complicated model of the patient in the software so that a sequence of moves or an entire therapeutic regime could be worked out at one time. Doing this, however, changes the objective; now, using the system would be a practice and learning experience rather than a tool to compute the next therapeutic step. This is what we have attempted in creating FLUIDMOD. Rather than merely selecting rules that cover a particular situation, FLUIDMOD computes the consequences of therapy, using the patient model, and presents these consequences to the student for his next decision. Patient data, data formats, time delays, therapeutic fluids, etc., are presented on the CRT in emulation of the actual clinical situation so that the student perforce must "treat" the case as though it were real. Certain remarkable or dangerous situations may be called to the student's attention, but otherwise the program will not branch to the instructional mode unless the student requests help. He may continue to treat the case until the "patient" either is out of trouble or dies. He also may treat the same patient over and over to compare different regimes, or he may go on to other cases. A simulated four-day "treatment" may be accomplished in a few minutes with the results charted, tabulated, and summarized as in the clinic.

III. FLUIDMOD

Quite obviously, the utility of such a system depends strongly upon the validity of the patient model. For this purpose, FLUIDMOD uses a complex chemical steady-state modeling program previously developed at The Rand Corporatio and at the Department of Thoracic Surgery, UCLA, and reported in, for example, Refs. 3 through 6. This program will compute the distribution of fluids and electrolytes in the rapidly exchanging body compartments (plasma, red cell, interstitial, and intracellular) under wide constraints and conditions -- in particular, over the viable range for human patients. In this model, constituents are distributed primarily by osmotic, electrical, and so-called "active" membrane forces. The model has been validated in a variety of circumstances.

This basic model forms the core of FLUIDMOD, but other compartments, organs, and functions play crucial roles in the control of fluid and electrolytes, for example, the lungs, kidney, skin, GI tract, and the metabolism. Therefore, in FLUIDMOD, each of these additional functions is emulated. Lung gases, skin losses, GI losses and gains, and metabolic products and rate may be specified arbitrarily for each patient or in some cases may be computed as a consequence of the current patient status. The kidney model is a behavioristic model whose function either is a consequence of current plasma status or may be overridden with patient urine data from an actual case.

In addition to these functions, the program includes the necessary control subprograms such as:

1. Doctor's orders
2. Nurses' notes
3. Patient record
4. Case history
5. Balance I/O
6. Chart
7. Graphs/plot
8. Kidney
9. Metabolic mix
10. Normal/scale
11. Output
12. Laboratory report
13. i.v. and p.o. fluids
14. Solve
15. Disease simulation
16. Help

These programs are called as required interactively as the student "treats" the "case" hour by hour (or, rather, calculation interval by calculation interval, since in actual practice the physician is not usually continuously present during treatment). We will briefly illustrate their use below.

FLUIDMOD is currently at this stage of development; that is, the student practice programs so far described have been incorporated, and students are using the system in order to check it out and to provide us with some appreciation of the remaining requirements, primarily smoothness of operation and speed of interaction. The instructional programs to which a student may branch have been written as textual material with graphs, photographs, and so on, but have not yet been incorporated in the program. We do not yet know the optimum method to accomplish this for maximum useful effect. In addition to being sufficiently profound and in the correct context to hold the student's attention, the system must be quite smooth in operation so that the student is not distracted from his therapeutic problem by computer details.

IV. EXAMPLE

Cases may be copies of interesting clinical situations or presentations of certain problems, such as cholera, hypokalemia, or hypernatremia. Cases are made up and stored in memory in advance. Students may then call them one at a time for practice treatment. In cases that are taken from the clinic, actual clinical data such as temperature, urinalysis, and weight loss may be used to modify the "patient" hour by hour.

For an example, the chemical equilibrium model is first automatically modified to simulate the current case disease state. Thus, it must be scaled to the weight of the patient and must incorporate the gains or losses of fluids and electrolytes shown by the patient on "admission" to the hospital. When the patient is admitted, the student first is shown a short history and physical exam on the CRT. He is then asked to give his first order. The sequence of physician's orders and the consequences thereof constitute the therapeutic course of patient management. Each order is a physician decision either to gather more information (by further testing) or to take a therapeutic action. Physician's orders, here, may be chosen from the following list:

0 = no further orders
1 = physical examination
2 = packed cell volume
3 = serum electrolytes and bun (1 hour)
4 = acid-base study (1 hour)
5 = urinalysis
6 = vital signs
7 = intake and output
8 = daily body weight
9 = i.v. fluids
10 = stop i.v.
11 = p.o. fluids
12 = NPO

Note that no drug therapy is available. That alternative will require considerable additional development of the system.

After presenting the data requested, the student is asked, What next?, to which he may make one of three responses:

1. Continue old orders
2. Enter new orders
3. Stop calculation

The course of therapy proceeds until either the student stops the calculation or the program hits a branch to stop for one reason or another. At this point, the course of therapy is summarized (usually on the high-speed printer). In this summary, the student will find the tabulated clinical laboratory data, progress notes, the collected doctor's orders, physical and vital signs, i.v. fluids, summarized medical record, and various charts and graphs which may be requested.

The card images of two experimental cases, not including the fluids for therapy, look as follows:

1. 10-kg child with vomit.ng and diarrhea

10.0	60.0	1.0	M

1Calint	6				
1Diarrhea	-25H_2O	55140Na+	40K+	40Cl-	40
1Diarrhea	HCO_3-	40			
8Vomitus	-20H_2O	55140Na+	80K+	20Cl-	80
8Vomitus	HCO_3-	20			
8Adm	4				

The patient is a 10.0-kg, one-year-old infant who has had a 2-day history of profuse watery diarrhea and poor food intake. For the 6 hours prior to admission, the infant has vomited all liquids which were offered to him.

9Urine	17H_2O	55140Na+	15K+	5Cl-	30
9Urine	H+	100organ-	90		
9Diarrhea	0				
9Vomitus	0				
97End					

2. 42 yr male with oliguria

50.0	150.0	42.0	M

1Calint	12				
1Urine	-150H_2O	55140Na+	60K+	30Cl-	60
1Urine	HCO_3-	30urea	6.67H+	20organ	20
1Adm	9				

The patient is a 50.0-kg, 42-year-old male who has had a 3-day history of severe oliguria due to acute tubular necrosis which was managed conservatively. On this, the fourth day, the urine volume suddenly increased so that over the past 12 hours, it has risen to a plateau of 150 ml/hr. A specimen showed the following composition:

Na+ = 60 meq/1
K+ = 30 meq/1
Cl- = 60 meq/1
NCO_3 = 30 meq/1

97end

In addition, however, the card images describing a case may specify temperature, metabolic rate, kidney function, lung or skin or GI losses, and so on. The numbers in columns 1 and 2 indicate the chronological times at which these changes will be inserted in the course of the case. Thus, there is the possibility of a certain arbitrariness or element of surprise which may be built into a case, as in the real situation. These data are stored either by case number or by name to be recalled by the student.

A typical physical exam as reported to the student might be:

Physical Examination

```
Time
 0  Pulse = 72   Resp = 20   Temp = 98.6   B.P. = 119/79
    Alert.  Skin pink, warm, and moist with good turgor.
    Skin does not tent.  Mucous membranes pink and moist.
    Peripheral pulses full.  Heart sounds normal.
```

A typical summarized list of doctor's orders as collected at the end might be:

Doctor's Orders

```
Time
 0    1) physical examination now
 0    2) HGB and HCT now
 0    3) routine urinalysis in 1 hr
 0    4) electrolytes and bun now
 0    5) acid-base study in 1 hr
 0    6) electrocardiogram in 2 hrs
 0    7) vital signs every 3 hrs
 0    8) measure intake and output
 0    9) daily body weights
 0   10) i.v. fluids
           500 ml pediasol M - D5W
           500 ml KCl  2 meq/ml
         run i.v. at 200 ml/hour
 1   11) D/C i.v.
 1   12) oral fluids
          1000 ml/24hrs enfamil
 1   13) NPO
```

```
1   14) i.v. fluids
            0 ml pediasol RB
          500 ml pediasol RB
        run i.v. at 200 ml/hour
1   15) HGB and HCT now
2   16) i.v. fluids
        same as order no. 14
3   17) i.v. fluids
        same as order no. 14
4   18) routine urinalysis now
4   19) electrolytes and bun now
4   20) acid-base study now
4   21) physical examination now
4   22) i.v. fluids
        same as order no. 14
5   23) i.v. fluids
        same as order no. 14
6   24) i.v. fluids
        same as order no. 14
7   25) i.v. fluids
        same as order no. 14
```

Comments from the computer might include the following:

Intake and output sheet has been ordered.

Daily body weights have been ordered.

The patient will receive nothing by mouth.

Hematology

Time	PCV	HGB
0	39.9	13.2

Electrolytes sent to lab -- results in 1 hr.

Acid-base study sent to lab -- results in 1 hr.

Urinalysis

Time	pH	Sp Grav	Gluc	Acet	Prot
3	6.5	0.999	0	0	0

With each doctor's order, the student is required to specify the time when it will be executed, in hours from the present. In the case of intravenous or parenteral fluids, he must also specify the amount and rate. The fluids available for therapy will vary somewhat with each patient. For example, there are special fluids for infants, different in some cases from those for adults.

Also, for particular cases, the fluids may be restricted in order to make the problem more difficult or because the natural choice is small or special. A typical list of i.v. and parenteral fluids for an infant is shown below:

<u>i.v. Fluids</u>

1. D5W
2. KCl 1 meq/ml
3. KCl 2 meq/ml
4. NaCl 1 meq/ml
5. NaCl 2 meq/ml
6. $NaHCO_3$ k meq/ml
7. Normal saline
8. NS - D2.5W
9. NS - D5W
10. NS - D10W
11. 1/2 NS
12. 1/2 NS - D2.5W
13. 1/2 NS - D5W
14. 1/4 NS - D5W
15. 5 percent $NaHCO_3$
16. 1/6 M Lactate
17. Normosol-M - D5W
18. Normosol-R
19. Normosol-R - D5W
20. Ringer's Lactate
21. Ring Lact - D5W
22. Ionosol B - D5W
23. Ionosol D - D10W
24. Ionosol G - D10W
25. Ionosol T - D5W
26. Ionosol MB - D5W
27. Ionosol PSL
28. Pediosol RB
29. Enfamil
30. Pediosol M - D5W

<u>Parenteral/Oral Fluids</u>

1. Milk
2. Water
3. Coca-cola
4. Ginger ale
5. Orange juice
6. Enfamil
7. Similac
8. Standard 2

When an order is given, the program notes the order and requests the next order. The student signals the end of the current orders by typing a 0 (zero). The program then computes the consequences and updates the simulated time. At the beginning of the next iteration (which may be a simulated hour or an interval later), results are presented as requested in the previous iteration. Nothing additional is volunteered by the program unless the "patient" is critical for one reason or another (hypovolemia, tachacardia, etc.) or unless the patient dies.

V. RESULTS AND CONCLUSIONS

The interactive program as described was written in FORTRAN and occupies about 200K bytes with overlay. It has been reasonably successful in that users at the console do get involved with the case under treatment. We are now planning an educational experiment in which a selected set of students will interact with a collection of cases. We hope to learn whether this system in its eventual form will be useful in a teaching-hospital environment. That environment is quite demanding in that the everyday problems of patient management are quite complex, the students are bright and will quickly discard a superficial aid, and the students value their available time highly. A teaching aid must be nontrivial; that is, it must be potentially dense with useful information, reasonably profound and problematical, able to contain random surprises, realistically challenging, relevant, and rewarding. This program is not yet all of that.

As noted, we have not yet incorporated the instructional sequences to which a student might branch. Although they are for the most part written by one of us (Winters), we are not sure how this information should be presented. In general, it is the interface I/O formats, hardware, and techniques which will require considerable thought. The same information presented in an ordinary textbook might be totally absorbing to the student but would not capture his interest written on a CRT.

Again, no matter how realistically the information about a patient is formatted on a CRT or printer output sheet, there is considerable information, and perhaps crucial information, missing unless the student can see and feel the patient. This difficulty for medical CAI devices is well known and is recognized by us. On the other hand, this difficulty is much more critical for, say, the diagnostic service than for fluid therapy. Fluid management can

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be and usually is an abstract problem in physical chemistry, biophysics, and theoretical physiology. The patient is an organized collection of compartments and functions and the problem is to create a viable balance of fluids and electrolytes by a combination of judicious additions plus advantageous use of the body's own predictable functions. In the future we may be able to construct a simulation of the several control systems, do parameter sensitivity analysis, and optimize the therapeutic trajectory. However, that is not now possible. At present, the physician makes the best hypothesis from the data available and tries a therapeutic course based upon his skill and training.

Because teaching programs like FLUIDMOD are abstract, it may be necessary to immerse the system in a carrousel in which slides or motion-picture projections of the patient are also available, or a simulated body such as SIM/1 (Ref. 7) may even be needed. However, the cost of such elaborate systems rapidly gets out of reasonable range. The current objective is to have the student sit at a console for a cost of less than one dollar per hour, and we have achieved that objective.

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